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The effect of genotype and agronomic factors on crop growth and yield in field peas (*Pisum sativum* L.) as influenced by radiation interception and utilisation

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Abstract

Three trials were conducted in 2006/07 and 2007/08 growing seasons aiming to find the effect of genotype, crop and weed population densities, herbicide, and sowing date on crop growth and yield in *Pisum sativum* as influenced by radiation interception and utilisation. The first experiment was a split plot with two cyanazine treatments as main plots. Subplots were a factorial combination of three pea genotypes and three plant population densities. Experiment 2 was also a split plot with three sowing dates as main plots. Sub-plots were a factorial combination of two pea genotypes, and two herbicide treatments. Experiment 3 treatments were a factorial combination of four pea populations and three sown artificial weed population densities arranged in a randomised complete block. Each of the three experiments had three replicates. Dry matter and radiation were measured throughout the growing season and seed yield was measured at harvest. There were significant ($p \leq 0.05$) herbicide by population interactions on total dry matter (TDM) and seed yield. Early pea sowing was associated with greater total radiation accumulation. The August sowing gave the highest seed yield 547 g m^{-2}, which was 45% more than the lowest yield in October. The higher yield was a result of increased accumulative radiation interception. Increased pea population density increased yield. However, very high density (400 plants m^{-2}) resulted in reduced seed yield.

Keywords: Cyanazine, genotype, herbicide, *Pisum sativum*, radiation interception, sowing date.
Abbreviations: CHI_crop harvest index, LAI_leaf area index, RUE_radiation use efficiency, TDM_ total dry matter.

Introduction

One of the most fundamental components driving crop growth is radiation interception (McKenzie, 1987; Sinclair and Muchow, 1999). To obtain maximum yield, the crop should competitively acquire as much leaf area early in its growth and achieve maximum canopy cover early to intercept as much radiation as possible. The trend in optimum crop production is for early sowing to optimise yield (Barrett and Witt, 1987, McDonald *et al*., 2007) because yield is increased when crops have a longer growing season resulting in increased intercepted radiation. Leaf area index (LAI) of a crop and plant canopy architecture determine the amount of light intercepted, which is directly related to total DM production (Montieth, 1977; Sinclair and Muchow, 1999). This then influences seed yield (Muchow *et al.*, 1993). Abbate et al. (1997) demonstrated that intercepted photosynthetically active radiation was the main factor determining crop growth in wheat. Crop growth and yield can also be enhanced by growing appropriate crop genotypes (Radosevich et al., 1997, Blackshaw et al., 2007) at the right sowing dates and seed rates. The use of a higher than normal seeding rate of 90 seed m^{-2} for conventional growing may be necessary to give a higher competitive ability in organic pea production (Grevsen, 2003) and this is due to the ability of higher crop populations to capture radiation at the expense of weeds. Peas can clearly out compete weeds for light if sown at a higher than normally recommended population (McDonald *et al.*, 2007). Several crops show genotypic differences in their competitive ability (Burnside, 1972; McDonald et al., 2007) and different weed species have different competitive abilities with crops (Harker et al., 2007). The objective of this research was to find the effect of genotype (leafed, semi leafless branched, semi leafless unbranched), crop and weed population densities, herbicide, and sowing date and the interactions on crop growth and yield in *Pisum sativum* as influenced by radiation interception and utilisation.

Results

Total Dry Matter

Until final harvest no factor influenced TDM throughout the 2006/07 season. At final harvest, there was a significant ($p \leq 0.05$) herbicide by population interaction (Table 2). This showed there was no significant difference in total DM in sprayed and unsprayed plots at 100 and 400 plants m^{-2}. However, at 50 plants m^{-2} the sprayed peas produced 30% more TDM (1,517 g m^{-2}) than unsprayed peas (1,162 g m^{-2}). In the 2007/08 season, total DM at final harvest of the August and September sowings were not significantly different from each other (mean 1,018 g m^{-2}) but both were significantly ($p \leq 0.05$) higher than in the October sowing (Table 3). Cyanazine sprayed plots produced 21% more TDM than unsprayed plots. There was no significant difference in the mean TDM produced by the two pea cultivars Midichi and Pro 7035 (mean 941 g m^{-2}). The highest TDM was achieved at 200 plants m^{-2} (1,120 gm^{-2}), which was more than twice the yield of the lowest pea

Table 1. Weather data for the 2006/07 and 2007/08 growing seasons for Lincoln University, Canterbury.

Month	Solar Radiation ($MJm^{-2}month^{-1}$)		Vapour Pressure (Pa)		Penman ET (mm)	
	2006/07	2007/08	2006/07	2007/08	2007/08	2007/08
September	375.1	369.9	9.2	9.2	87.5	73.9
October	542.9	570.0	9.4	9.0	120.8	123.5
November	633.3	705.5	10.8	11.0	127.7	131.8
December	648.8	711.2	11.3	13.6	126.1	141.2
January	585.5	698.4	13.7	14.3	115.2	151.7
February	511.1	530.2	14.1	14.2	102.8	113.7

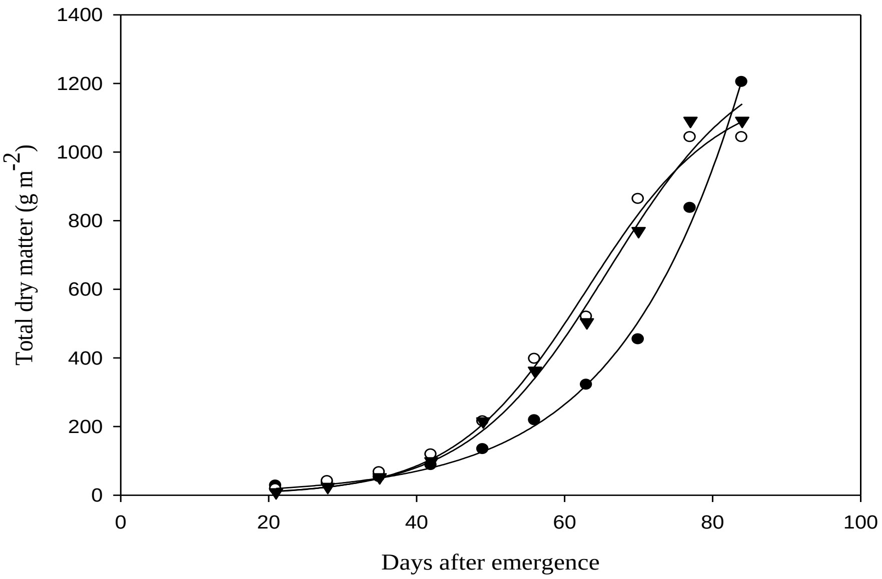

Fig 1. Total dry matter accumulation of field peas, over time, grown in Canterbury in the 2007/08 growing season, sowing date.
(●) = August sowing, $Y = 1660 / (1 + 1.99 \exp(-0.12(x-83.59)))^{1/1.99}$
(○) = September sowing $Y = 1116 / (1 + 1.27 \exp(-0.12(x-63.42)))^{1/1.27}$
(▼) = October sowing $Y = 1325 / (1 + 0.56 \exp(-0.08(x-64.8)))^{1/0.56}$

population (513 g m^{-2}) with weed treatments (Table 4). The no-sown-weed treatment gave the highest mean TDM (1,041 gm^{-2}).

Seed Yield

In the 2006/07 season herbicide had no effect on seed yield and the overall mean was 673 g m^{-2}, (Table 2). There was also no significant seed yield difference among the pea genotypes, Aragorn, Pro 7035 and Midichi. However there was a significant ($p \leq 0.05$) herbicide by population interaction. Herbicide had no effect on seed yield at 100 and 400 plants m^{-2} but at 50 plants m^{-2} cyanazine treated plots produced 829 g m^{-2} of seed, which was 30% more than the 637 g m^{-2}, produced in the no herbicide treatment.

In 2007/08, herbicide sprayed peas had a mean seed yield of 508 g m^{-2}. This was 19% more than the mean pea yield of the unsprayed plots (Table 3). A significant ($p \leq 0.05$) sowing date x pea genotype interaction showed that in the August sowing genotype had no effect on seed yield. However, in September plots sown in Pro 7035 yielded 559 g m^{-2}, which was 40% more than Midichi and in the October sowing, the difference was 87% more. In the population experiment seed yield increased significantly ($p \leq 0.001$) as pea population increased. Two hundred pea plants m^{-2} gave the highest mean seed yield at 409 g m^{-2} and 50 pea plants m^{-2} the lowest at 197 g m^{-2}. On the other hand the no-sown-weed control gave the highest mean seed yield of 390 g m^{-2}.

Crop Harvest Index

In both seasons herbicide had no effect on CHI. In 2006/07 CHI was in the order: Aragorn (0.48) < Midichi (0.52) < Pro 7035 (0.55). In the 2007/08 season the significant sowing date x genotype interactions for CHI showed that in an August sowing there was less difference in CHI between the two cultivars than at the other two sowing dates.

DM Accumulation and functional growth analysis

A significant ($p \leq 0.05$) herbicide x pea genotype interaction showed that the maximum DM of Pro 7035 was similar in the cyanazine sprayed and unsprayed peas (Table 5). However the maximum DM of cyanazine sprayed Midichi plots was 31% higher than that of the unsprayed ones. A significant ($p \leq 0.05$) herbicide x pea genotype interaction showed that Pro 7035 grew 55% faster than Midichi in unsprayed plots but they had an almost equal WMAGR in sprayed plots. In experiment 3 the highest WMAGR (18.4 g m^{-2} d^{-1}) was achieved at the highest pea population (200 plants m^{-2}) and the two lowest populations had no significant difference (mean 9.5 g m^{-2} d^{-1}) (Table 6). Sown weed population did not

Table 2. Total dry matter (TDM), seed yield, and crop harvest index (CHI) at final harvest (126 DAE) of field peas grown in Canterbury in the 2006/07 growing season (Experiment 1).

Treatments	TDM ($g\ m^{-2}$)	Seed yield ($g\ m^{-2}$)	CHI
Herbicide (H)			
0 g a.i.ha^{-1}	1,255	647	0.52
500 g a.i.ha^{-1}	1,349	700	0.52
Significance	NS	NS	NS
LSD	-	-	-
Population(P) (plants m^{-2})			
50	1,339	733b	0.55c
100	1,288	681ab	0.53b
400	1,278	606a	0.47a
Significance	NS	*	***
LSD	-	89	0.02
Type(T)			
Pro 7035	1,322	729	0.55c
Aragorn	1,321	628	0.48a
Midichi	1,262	663	0.52b
Significance	NS	NS	***
LSD	-	-	0.02
CV (%)	19.1	19.5	6.1
Significant interactions	HxP*	HxP*	Nil

NS=Not significant at 0.05; *p<0.05, **p<0.01, ***p<0.001.

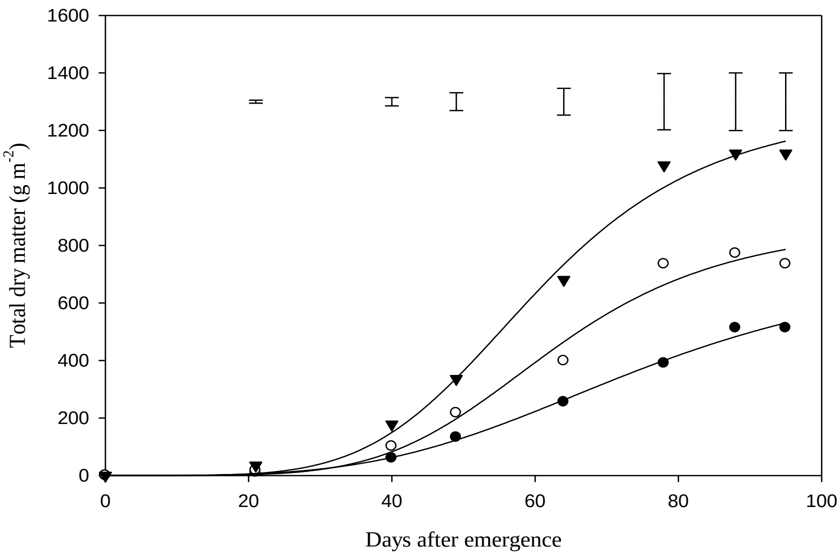

Fig 2. Total dry matter accumulation of field peas, over time, grown in Canterbury in the 2007/08 growing season, pea population.
(●) = 50 plants m^{-2}, $Y = 632 / (1 + 0.44 \exp(-0.05(x-65.2)))^{1/0.44}$
(○) = 100 plants m^{-2}, $Y = 840 / (1 + 0.66 \exp(-0.07(x-60.9)))^{1/0.66}$
(▾) = 200 plants m^{-2}, $Y = 1215 / (1 + 0.91 \exp(-0.08(x-59.6)))^{1/0.91}$
(Bars are LSD at $p \leq 0.05$).

affect WMAGR and the means ranged from 10.8 – 13.2 $g\ m^{-2}\ d^{-1}$. The highest maximum DM was achieved at 200 plants m^{-2} (1,164 $g\ m^{-2}$) and the two lowest populations had similar maximum DM (mean 740 $g\ m^{-2}$). The no-sown-weed treatment gave the highest mean maximum DM (1,169 $g\ m^{-2}$). No factor significantly affected DUR and it ranged from 70 – 103 d.

Total radiation interception, radiation use efficiency

Tables 7 and 8 show total radiation interception and radiation use efficiency in the 2007/08 season. Early sowing had higher total radiation interception than the late sowing. Radiation interception was directly proportional to pea population and the sown weed treatment did not affect pea cumulative radiation interception. There was a herbicide x pea genotype interaction on RUE. The mean RUEs of herbicide sprayed and unsprayed Pro 7035 plots were not significantly different. However, herbicide sprayed Midichi plots had a 29% higher RUE than unsprayed plots. On the other hand RUE increased with increased pea population. The RUE increased by 48% as population increased from 50 plants m^{-2} to 100 plants m^{-2} and by a further 41% as pea population increased from 100 plants m^{-2} to 200 plants m^{-2}. Sown artificial weed population did not affect RUE and it

Table 3. Total dry matter, seed yield, crop harvest indices at final harvest of field peas grown in Canterbury in the 2007/08 growing season (Experiment 2).

Treatments	TDM (g m^{-2})	Seed yield (gm^{-2})	CHI
Sowing date (S)			
August	1005b	572b	0.57b
September	1031b	479b	0.47ab
October	788a	354a	0.44a
Significance	*	**	**
LSD	192.9	94.7	0.04
Herbicide (H)			
0 g a.i. ha^{-1}	852	428	0.50
500 g a.i. ha^{-1}	1030	508	0.49
Significance	***	***	NS
LSD	94.4	43.8	-
Pea type (T)			
Midichi	911	398	0.43
Pro 7035	971	539	0.56
Significance	NS	***	***
LSD	-	43.8	0.02
CV (%)	14.3	13.4	5.6
Significant interactions	Nil	SxT*	SxT***

NS=Not significant at 0.05; *p<0.05, **p<0.01, ***p<0.001

Table 4. Total dry matter seed yield and crop harvest index (CHI)) at final harvest of field peas grown in Canterbury in the 2007/08 growing season (Experiment 3).

Treatments	Total dry matter (g m^{-2})	Seed yield (g m^{-2})	CHI
Pea population (P) (plants m^{-2})			
50	513a	197a	0.39
100	735b	294b	0.40
200	1,120c	409c	0.37
Significance	***	***	NS
LSD	200.4	71	-
Sown weed population (W)			
Nil	1,041b	390b	0.39
Low weed rate	712a	284a	0.40
High weed rate	616a	226a	0.37
Significance	***	***	NS
LSD	200.4	71.0	-
CV (%)	25.4	23.7	10.4
Significant interactions	Nil	Nil	Nil

NS=Not significant at 0.05; *p<0.05, **p<0.01, ***p<0.001.

ranged from 1.03 g MJ^{-1} in the 2X normal weed seed rate to 1.16 g MJ^{-1} in no sown artificial weed treatment.

Discussion

There were few significant treatment effects in 2006/07 mainly because there was little competition from weeds at the site. However, increased crop population resulted in reduced seed yield with the highest yield 733 g m^{-2} produced by the lowest population. Under low weed pressure it is therefore prudent to use lower sowing rate because of compensatory effect of yield components especially when seed cost is high (Askin et al., 1985). At high populations there was self-thinning and this resulted in reduced final plant populations. The significant ($p \leq 0.05$) herbicide by population interaction on mean seed yield in the 2006/07 season, indicated that herbicide had no effect on seed yield at 100 and 400 plants m^{-2} but at 50 plants m^{-2} seed yield was significantly increased with herbicide. This meant that at very low crop population (50 plants m^{-2}) weed competition was high enough to reduce yield. There was no difference in seed yield between the three cultivars in 2006/07. Comparative studies in England (Heath et al., 1991) and Scotland (Taylor et al., 1991) demonstrated that semi-leafless peas and leafed peas were relatively unresponsive to plant density and semi-leafless peas gave seed yields similar to the leafed variety. Despite the general high yields obtained in this research, pea yields have often been reported to be variable (Wilson, 1987; Moot, 1993; Moot and McNeil, 1995; Timmerman-Vaughan et al., 2005) usually due to variability in harvest index. Under this CHI was relatively not so variable in both seasons (ranged from 0.48 to 0.56). Pro7035 achieved a higher CHI than Midichi and that resulted in the higher seed yield even though total DM was not affected. Early sowing was shown to increase yield under this research. McKenzie (1987) reported that in temperate countries with even, dependable rainfall, early sowing allows crops to produce large plants which can produce and support many pods, and which

Table 5. Functional growth analysis of field peas grown in Canterbury in the 2007/08 growing season (Experiment 2).

Treatments	Max DM (g m^{-2})	WMAGR (g $m^{-2}d^{-1}$)	C_m (g $m^{-2}d^{-1}$)	DUR (d)
Sowing date (S)				
August	1260	18.58	33.1	71.8
September	1061	18.72	32.7	58.4
October	1161	17.67	27.4	65.0
Significance	NS	NS	NS	NS
LSD	-	-	-	-
Herbicide (H)				
0 g a.i. ha^{-1}	1106	16.92	28.2	67.8
500 g a.i. ha^{-1}	1215	19.74	34.0	62.3
Significance	NS	NS	*	NS
LSD	-	-	4.5	-
Pea genotype (T)				
Midichi	1161	16.68	30.6	71.5
Pro 7035	1161	19.98	31.6	58.6
Significance	NS	NS	NS	NS
LSD	-	-	-	-
CV (%)	19.2	29.7	20.3	30.3
Significant interactions	HxT*	HxT*	HxT*	Nil

NS=Not significant at 0.05; *p<0.05, **p<0.01, ***p<0.001. WMAGR = Weighted mean absolute growth rate. DUR = Duration of exponential growth. C_m = Maximum growth rate. Max DM = Maximum dry matter.

Table 6. Functional growth analysis of field peas grown in Canterbury in the 2007/08 growing season (Experiment 3).

Treatments	WMAGR (g m^{-2} d^{-1})	C_m (g m^{-2} d^{-1})	Max DM(g m^{-2})	DUR (d)
Pea population (P) (plants m^{-2})				
50	8.4a	12.9a	613a	97
100	10.6a	15.8a	866a	91
200	18.4b	29.1b	1,164b	78
Significance	**	*	***	NS
LSD	6.2	10.7	235	-
Sown weed population (W)				
Nil	13.2	19.8	1,169b	103
Low weed rate	13.4	20.9	781a	70
High weed rate	10.8	17.2	694a	93
Significance	NS	NS	***	NS
LSD	-	-	235	-
CV (%)	49.6	55.4	26.7	46.6
Significant interactions	Nil	Nil	Nil	Nil

NS=Not significant at 0.05; *p<0.05, **p<0.01, ***p<0.001, WMAGR = Weighted mean absolute growth rate. DUR = Duration of exponential growth , C_m = Maximum growth rate, Max DM = Maximum dry matter

intercept maximum solar radiation through longer duration and more rapid early spring growth. The results of this experiment support this particularly with the semi leafless Midichi. The August sowing gave the highest seed yield 547 g m^{-2}, which was 45% more than the lowest yield in October. The August sowing accumulated the most intercepted radiation as a result of the highest leaf area index. Crop leaf area index and plant canopy architecture determine the amount of light intercepted, which is directly related to TDM production (McKenzie, 1987; Sinclair and Muchow, 1999). This in turn influences seed yield (Muchow et al., 1993). The higher yield associated with the earlier sowing in this research was primarily due to increased radiation interception since sowing date was found to have no effect on RUE. The RUE ranged from 1.79 g MJ^{-1} in August to 1.94 g MJ^{-1} in October. Pea genotype alone did not affect RUE. This supports Martin et al. (1992), who showed that at similar densities, all pea phenotypes converted intercepted radiation into DM with equal photosynthetic efficiency and that the foliage of leafless peas was not a photosynthetic disadvantage. Radiation use efficiencies ranged from 1.79 – 1.94 g MJ^{-1}. Wilson et al. (1985) showed that cumulative DM production in peas was linearly related to the amount of PAR intercepted by the crop. They obtained a radiation use efficiency of 2.36 g MJ^{-1}. Heath and Hebblethwaite, (1985) reported a lower RUE for peas (1.46 g MJ^{-1}). RUEs were in the range of 1.0 – 2.5 g MJ^{-1} in Zain et al. (1983) for a range of irrigation and sowing date treatments. McKenzie and Hill (1991) reported the RUE of lentil to be in a range of 1.6 – 1.8 g MJ^{-1}. Similarly, McKenzie (1987) reported RUEs of 2.05

Table 7. Total radiation interception and radiation use efficiency (RUE) of field peas grown in Canterbury in the 2007/08 growing season (Experiment 2).

Treatments	Total Radiation Interception (MJ m^{-2})	RUE (g MJ $^{-1}$)
Sowing date (S)		
August	622.1	1.79
September	612.9	1.81
October	531.2	1.94
Significance	*	NS
LSD	51.5	-
Herbicide (H)		
0 g a.i. ha^{-1}	593.1	1.74
500 g a.i. ha^{-1}	584.3	1.95
Significance	NS	*
LSD	-	0.17
Pea genotype (T)		
Midichi	589.0	1.85
Pro 7035	588.4	1.84
Significance	NS	NS
LSD	-	-
CV (%)	4.8	13.4
Significant interactions	Nil	HxT**

NS=Not significant at 0.05; *p<0.05, **p<0.01, ***p<0.001.

Table 8. Radiation Use efficiency of field peas grown in Canterbury in the 2007/08 growing season (Experiment 3).

Treatments	Total Radiation Interception (MJ m^{-2})	Radiation Use efficiency (g MJ^{-1})
Pea population (P) (plants m^{-2})		
50	272a	0.73a
100	380b	1.08b
200	482c	1.52c
Significance	***	***
LSD	82.1	0.25
Sown weed population (W)		
Nil	430	1.16
Low weed rate	385	1.15
High weed rate	371	1.03
Significance	NS	NS
LSD	-	-
CV (%)	13	22
Significant interactions	Nil	Nil

NS=Not significant at 0.05; *p<0.05, **p<0.01, ***p<0.001.

and 1.51 in irrigated and unirrigated lentil respectively. Generally the high sowing rates required to obtain an acceptable yield per unit area of leafless peas can be interpreted as a requirement to increase crop growth rate (CGR), especially early in crop development (Hedley and Ambrose, 1981). In this experiment sowing date did not affect WMAGR and the overall mean was 18.3 g m^{-2} day^{-1}. Similarly, Greven, (2000) reported no sowing date effect on the WMAGR of *Phaseolus vulgaris* grown in Canterbury. The significant ($p \leq 0.05$) herbicide x genotype interaction showed that Pro 7035 grew 55% faster than Midichi in unsprayed plots but had a similar WMAGR in cyanizine sprayed plots. This could be due to reduced competitive ability of semi-leafless peas against weeds in later sowings because of its semi-leafless morphology. The leafed pea tended to outdo semi-leafless performance in the presence of weeds though their performance was similar in a weed free environment. In the other experiment, growth analysis showed no treatments affected growth rates or DUR except for herbicide and the herbicide x genotype interaction. The factors that had the major effect were radiation interception for TDM and HI for seed yield. Increasing population gave increased radiation interception and increased yield due to earlier LAI and decreased weeds. For high yields, crops should quickly produce enough LAI to intercept most of the incident light (Ayaz, 2001) after which they should maintain high levels of interception and partition as much assimilate as possible to reproductive organs (Gardner et al., 1985). The amount of DM accumulated by a crop is strongly related to the total intercepted solar radiation, by the crop, over the growing season (Monteith, 1977; Sinclair and Muchow, 1999). The yield results are very consistent in the second year with both seed yield and TDM related to increased growth rate due to increased radiation interception.

Materials and Methods

Climate

Climate data was from the Broadfields Meteorological Station, Lincoln University located about 1.5 km from the experimental site. The 2006/07 season was generally dry at the beginning. However, there was substantial rain in December (110.6 mm) and October (97.6 mm), when almost double the long-term average fell. In the 2007/08 growing season rainfall was below long-term average early in the season, August and September. Substantial rainfall was received in February doubling the long-term average. Both seasons were generally cooler than the long-term average. Solar radiation, vapour pressure deficit and evapotranspiration data for both seasons is presented in Table 1.

Plant materials

Trials were conducted on a Templeton silt loam soil (New Zealand Soil Bureau, 1968) at the Horticulture Research Area, Lincoln University, Canterbury, New Zealand (43 ^{o} 38'S, 172 ^{o} 28' E.) in 2006/07 season (Experiment 1) and 2007/08 season (Experiments 2 and 3). Establishment of actual soil available nutrient levels was done by MAF soil quick tests were done. All the nutrient levels were in the acceptable range for growing peas and the pH was also optimal. The 2006/07 experiment was a split plot design with three replicates. Main plots were two herbicide treatments (cyanazine at 0 or 500 g a.i. ha^{-1}) applied before emergence. Subplots were a factorial combination of three pea genotypes; conventional (Pro 7035), semi-leafless branched (Aragorn) and semi-leafless unbranched (Midichi) and three plant populations; 0.5 x recommended sowing rate (50 plants m^{-2}), recommended sowing rate (100 plants m^{-2}) and 4.0 x recommended sowing rate (400 plants m^{-2}). Controls were plots without peas, which were sprayed or not sprayed with cyanazine, a total of 60 plots. Plots were 2.1 m wide x 8 m long. In experiment 2 (2007/08) treatments were also arranged in a split plot design with three replicates. Main plots were sown on 9 August, 13 September and 15 October 2007. Sub-plots were a factorial combination of two pea genotypes, conventional (Pro 7035) and semi-leafless (Midichi) and two herbicide treatments (cyanazine at 0 and 500 g a.i. ha^{-1}) applied before emergence. The total number of plots was 54 (36 plots with peas and 18 no pea control plots). Each plot was 2.1 m wide x 10 m long. Experiment 3 was sown on 13 September and the treatments were a factorial combination of four pea populations 0, 0.5 x recommended sowing rate recommended sowing rate (100 plants m^{-2}), 2.0 x recommended, and three sown artificial weed populations 0, 1/3 recommended (referred to here as lower rate) and 2/3 recommended (referred to here as higher rate) of each weed. The sown artificial weeds were a mixture of *Brassica napus*, *Lolium multiflorum* and *Vicia sativa* which had recommended sowing rates of 3, 25 and 30 kg ha^{-1} respectively. This was a good representation of a broad spectrum of weeds commonly found in most fields. The experiment design was a randomised complete block with three replicates. The total number of plots was 36. Each plot was 2.1 m x 6 m long. The field pea variety used was Midichi (a semi-leafless type).

Crop husbandry

The land was disked, rolled and harrowed (conventional land preparation method). It was tilled to a depth 25 cm. A pre-emergence spray of cyanazine at 500 g a.i.ha^{-1} was applied in 237 l water ha^{-1} to 30 of the 60 plots of experiment 1, to create the main plots. An Öyjord cone seeder was used to drill seed at a depth of 5 cm. For experiment 1 seed was sown on 12 September, 2006 in 15 cm rows with varying inter-row spacing to achieve the required pea populations of 50, 100 and 400 peas m^{-2}. In experiment 2, seed was sown in 15 cm rows and was sown at 100 plants m^{-2} at the above-stated sowing dates. Cyanazine was applied pre-emergence to target plots at 500 g a.i. ha^{-1} with a knapsack sprayer. A formulated mixture of Metalaxyl, Fludioxonil (Wakil) and Cymoxanil for the control of *Peronospora* spp (downy mildew), *Pythium* spp and *Ascochyta* spp, was applied to all seed at the equivalent of 2 kg t^{-1} of seed before sowing. Experiment 3 was sown in 15 cm rows with varying inter row spacing to achieve pea populations of 50, 100 and 200 plants m^{-2}. The sown weed seed was then broadcasted onto plots and a lightly harrowed to incorporate them into the soil. Sowing rate was corrected for germination percentage and expected field emergence for all experiments. Irrigation was applied based on crop requirement as determined by Time Domain Reflectometry (TDR) in the 0 – 20 cm soil layer, when the soil reached 50% of field capacity. A mini boom irrigator applied 30 mm of water at each irrigation, a total of 90 mm during the first season and a total of 120 mm in the second season. The peas were sprayed with Alto (cyproconazole) 100 SL at 250 ml ha^{-1} to combat powdery mildew (*Erysiphe* spp) and with copper oxychloride at 1 kg ha^{-1} for downy mildew in both seasons.

Measurements and analysis

LAI was measured non-destructively using a LICOR LAI 2000 Plant Canopy Analyser every 7 – 10 days throughout the growing season starting from three weeks after crop emergence. Two readings were taken randomly above and eight beneath the crop canopy from each plot. This was done on either a uniformly cloudy day or at dusk. A 0.2 m^{2} sample for DM yield was taken from each plot using a 0.1 m^{2} quadrat every 7-10 days throughout the season starting from three weeks after crop emergence. Samples were dried in a forced draught oven for 24 – 48 h at 60 ^{o}C to a constant weight and then weighed. Yield and yield components were measured at harvest. Final harvests were taken when crops reached a moisture content of 15 – 18%. Final seed yield and TDM were estimated from 1 m^{2} quadrat samples. Plants were cut at ground level and weighed. They were hand threshed and the seeds weighed. Five plants were selected from the bulk sample and were used to calculate yield components.

All data were subjected to analysis of variance (ANOVA). Genstat 10.1. Copyright 2007, Lawes Agricultural Trust (Rothamsted Experimental Station) was used for statistical analysis. Means were separated at the 5% level of significance using least significance difference (LSD) for sowing date, herbicide, genotype, population and interactions effects.

Radiation Measurements

Radiation interception

The amount of photosynthetically active radiation (PAR) intercepted was calculated from Szeicz (1974):

Sa = Fi x Si x 0.5…………………..Equation 1

Where the Sa is the PAR and Si is the total incident solar radiation, which was recorded at Broadfields Meteorological station from crop emergence to crop physiological maturity.

The proportion of radiation intercepted (Fi) by the canopy was calculated according to Gallagher and Biscoe (1978):

Fi = 1.0 – T_i…………………………Equation 2

Where T_i is the amount of radiation transmitted through the canopy.

Radiation use efficiency (RUE) was obtained from the slope of regressions of crop DM on intercepted PAR from seedling emergence to crop maturity. In Experiments 2 and 3 functional growth analysis was done using the maximum likelihood program (MLP) from Rothamsted Experimental Station, United Kingdom (*Ross et al.*, 1987). Generalised logistic curves were fitted to the majority of the growth analysis data using the method of Gallagher and Robson (1984).

$Y = C / (1 + T \exp(-b(x-m)))^{1/T}$……………………Equation 3

where Y is yield, C is the final above ground DM and T, b and m are constants.

The values of C, T, b and m were used to derive the weighted mean absolute growth rate (WMAGR - the mean growth rate over the period when the crop accumulated most of its DM), duration of exponential growth (DUR - duration of crop growth over which most growth occurred) and the maximum crop growth rate (C_m) using the following equations:

$WMAGR = bC / 2(T + 2)$………………………….Equation 4

$C_m = bC / (T+1)^{(T + 1/T)}$ ……………………………Equation 5

$DUR = 2(T + 2) / b$………………………………..Equation 6

The remaining data were fitted to a Gompetz function (Equation 3.8) (Causton and Venus, 1981).

$Y = C \exp(-\exp(-b(x-m)))$………………………..Equation 7

where Y is the yield, C is the final DM and b and m are constants.

The WMAGR, DUR and Cm for TDM were derived from the below equations: (Pagelow Jr. *et al*., 1977).

$WMAGR = bC/4$ …………………………...........Equation 8

$DUR = 4/b$…………………………………………Equation 9

$Cm = bC/e$ ……………………………………... Equation 10

where e is the natural logarithm base and equals approximately 2.71828.

All data were subjected to analysis of variance (ANOVA). Genstat 10.1. Copyright 2007, Lawes Agricultural Trust (Rothamsted Experimental Station) was used for statistical analysis. Means were separated at the 5% level of significance using least significance difference (LSD) for herbicide main effects, population, type and interactions effect in the first season for sowing date main effects, herbicide, genotype and interactions effect in the other season.

Conclusions

Increased pea sowing rates increased yield due to increased radiation interception and decreased weeds. However, very high crop sowing rates (400 plants m^{-2}) resulted in reduced seed yield. There was a significant sowing date x genotype on seed yield that indicated the need to use specific genotypes for different sowing times. Early sowing was shown to increase yield particularly of the semi leafless Midichi. The August sowing gave the highest seed yield 547 g m^{-2}, which was 45% more than the lowest yield in October. The higher yield was a result of increased accumulative radiation interception. Major yield driving factors under this research were radiation interception for TDM and HI for seed yield. There was no significant difference in total radiation intercepted by semi-leafless and fully leaved pea genotypes hence similar TDM. Increasing population gave increased radiation interception and increased yield due to earlier LAI and decreased weeds. Cyanazine use increased yield particularly under low crop and later sowing dates.

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